

Chapter 5. Paved Roads

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5.1 Characterization of Source Emissions

Particulate emissions occur whenever vehicles travel over a paved surface such as a road or parking lot. Particulate emissions from paved roads are due to direct emissions from vehicles in the form of exhaust, brake wear and tire wear emissions, and resuspension of loose material on the road surface. In general terms, resuspended particulate emissions from paved roads originate from, and result in the depletion of the loose material present on the surface (i.e., the surface loading). In turn, that surface loading is continuously replenished by other sources. At industrial sites, surface loading is replenished by spillage of material and trackout from unpaved roads and staging areas.

Various field studies have found that public streets and highways as well as roadways at industrial facilities can be major sources of the atmospheric particulate matter within an area.¹⁻⁹ Of particular interest in many parts of the United States are the increased levels of emissions from public paved roads when the equilibrium between deposition and removal processes is upset. This situation can occur for various reasons, including application of granular materials for snow and ice control, mud/dirt carryout from construction activities in the area, and deposition from wind and/or water erosion of surrounding unstabilized areas. In the absence of continuous addition of fresh material (through localized trackout or application of antiskid material), paved road surface loading should reach an equilibrium value in which the amount of material resuspended matches the amount replenished. The equilibrium surface loading value depends upon numerous factors. It is believed that the most important factors are: the mean speed of vehicles traveling the road, the average daily traffic (ADT), the number of lanes and ADT per lane, the fraction of heavy vehicles (buses and trucks), and the presence or absence of curbs, storm sewers and parking lanes.¹⁰

5.2 Emissions Estimation: Primary Methodology¹⁻²⁸

This section was adapted from Section 13.2.1 of EPA's *Compilation of Air Pollutant Emission Factors (AP-42)*. Section 13.2.1 was last updated in December 2003.

Dust emissions from paved roads have been found to vary with what is termed the "silt loading" present on the road surface as well as the average weight of vehicles traveling the road. The term silt loading (sL) refers to the mass of silt-size material (equal to or less than 75 micrometers [μm] in physical diameter) per unit area of the travel surface. The total road surface dust loading consists of loose material that can be collected by broom sweeping and vacuuming of the traveled portion of the paved road. The silt fraction is determined by measuring the proportion of the loose dry surface dust that passes through a 200-mesh screen using the ASTM-C-136 method. Silt loading is the product of the silt fraction and the total loading, and is abbreviated "sL." Additional details on the sampling and analysis of such material are provided in AP-42 Appendices C.1 and C.2. A method developed by Desert Research Institute (DRI) to obtain real-time measurements of silt loading is discussed in Appendix B.

The surface silt loading (sL) provides a reasonable means of characterizing seasonal variability in a paved road emission inventory. In many areas of the country, road surface silt loadings are heaviest during the late winter and early spring months when the residual loading from snow/ice controls is greatest.¹¹⁻²¹ As noted earlier, once replenishment of fresh material is eliminated, the road surface silt loading can be expected to reach an equilibrium value, which is substantially lower than the late winter/early spring values.

The quantity of particulate emissions from resuspension of loose material on the road surface due to vehicle travel on a dry paved road may be estimated using the following empirical expression:

$$E = k \left(\frac{sL}{2} \right)^{0.65} \times \left(\frac{W}{3} \right)^{1.5} - C \quad (1)$$

where,

- E = particulate emission factor (having units matching the units of k),
- k = particle size multiplier for particle size range,
- sL = road surface silt loading (grams per square meter, g/m^2),
- W = average weight (tons) of the vehicles traveling the road, and
- C = emission factor for 1980's vehicle fleet exhaust, brake wear and tire wear.²⁷

It is important to note that Equation 1 calls for the average weight of all vehicles traveling the road. For example, if 99% of traffic on the road are 2-ton cars/trucks while the remaining 1% consists of 20-ton trucks, then the mean weight "W" is 2.2 tons. More specifically, Equation 1 is not intended to be used to calculate a separate emission factor for each vehicle weight class. Instead, only one emission factor should be calculated to represent the "fleet" average weight of all vehicles traveling the road.

The particle size multiplier (k) above varies with aerodynamic size range as shown in Table 5-1. To determine particulate emissions for a specific particle size range, use the appropriate value of k shown in Table 5-1.

The emission factor for the exhaust, brake wear and tire wear of a 1980's vehicle fleet (C) was obtained from EPA's MOBILE6.2 model.²⁸ The emission factor also varies with aerodynamic size range as shown in Table 5-2. Equation 1 is based on a regression analysis of numerous emission tests, including 65 tests for PM₁₀.¹⁰ Sources tested include public paved roads, as well as controlled and uncontrolled industrial paved roads. All sources tested were of freely flowing vehicles traveling at constant speed on relatively level roads. No tests of "stop-and-go" traffic or vehicles under load were available for inclusion in the data base. The equation retains the quality rating of A (B for PM_{2.5}), if applied within the range of source conditions that were tested in developing the equation, as follows:

- Silt loading: 0.03 - 400 g/m^2 ; 0.04 - 570 grains/square foot
- Mean vehicle weight: 1.8 - 38 megagrams; 2.0 - 42 tons
- Mean vehicle speed: 16 - 88 kilometers per hour; 10 - 55 miles per hour

Table 5-1. Particle Size Multipliers for Paved Road Equation

Size range ^a	Particle size multiplier k ^b		
	g/VKT	g/VMT	lb/VMT
PM2.5 ^c	1.1	1.8	0.0040
PM10	4.6	7.3	0.016
PM15	5.5	9.0	0.020
PM30 ^d	24	38	0.082

^a Refers to airborne particulate matter (PM_x) with an aerodynamic diameter equal to or less than x micrometers (μm).

^b Units shown are grams per vehicle kilometer traveled (g/VKT), grams per vehicle mile traveled (g/VMT), and pounds per vehicle mile traveled (lb/VMT). The multiplier k includes unit conversions to produce emission factors in the units shown for the indicated size range from the mixed units required in Equation 1.

^c Extrapolated from PM2.5 to PM10 ratio taken from Reference 22.

^d PM30 is sometimes termed “suspendable particulate” (SP) and is often used as a surrogate for total suspended particulate (TSP).

Table 5-2. Emission Factor for 1980’s Vehicle Fleet Exhaust, Brake Wear, and Tire Wear

Particle size range ^a	C, Emission factor for exhaust, brake wear, and tire wear ^b		
	g/VMT	g/VKT	lb/VMT
PM2.5	0.1617	0.1005	0.00036
PM10	0.2119	0.1317	0.00047
PM15	0.2119	0.13.17	0.00047
PM30 ^c	0.2119	0.1317	0.00047

^a Refers to airborne particulate matter (PM_x) with an aerodynamic diameter equal to or less than x micrometers (μm)..

^b Units shown are grams per vehicle kilometer traveled (g/VKT), grams per vehicle mile traveled (g/VMT), and pounds per vehicle mile traveled (lb/VMT).

^c PM30 is sometimes termed “suspendable particulate” (SP) and is often used as a surrogate for total suspended particulate (TSP).

NOTE: There may be situations where low silt loading and/or low average weight will yield calculated negative emissions from Equation 1. If this occurs, the emissions calculated from Equation 1 should be set to zero.

Users are cautioned that application of Equation 1 outside of the range of variables and operating conditions specified above (e.g., application to roadways or road networks with speeds below 10 mph and with stop-and-go traffic) will result in emission estimates with a higher level of uncertainty.

To retain the quality rating of A for PM10 (quality rating of B for PM2.5) for the emission factor equation when it is applied to a specific paved road, it is necessary that reliable correction parameter values for the specific road in question be determined. With the exception of limited access roadways, which are difficult to sample, the collection and use of site-specific silt loading (sL) data for public paved road emission inventories

are strongly recommended. The field and laboratory procedures for determining surface material silt content and surface dust loading are summarized in Appendices C.1 and C.2 of AP-42. In the event that site-specific silt loading values cannot be obtained, an appropriate value for a paved public road may be selected from the default values given in Table 5-3, but the quality rating of the equation should be reduced by two levels. Also, recall that Equation 1 refers to emissions due to freely flowing (not stop-and-go) traffic at constant speed on level roads.

Equation 1 may be extrapolated to average uncontrolled conditions (but including natural mitigation) under the simplifying assumption that annual (or other long-term) average emissions are inversely proportional to the frequency of measurable (at least 0.254 mm [0.01 inch]) precipitation by application of a precipitation correction term. The precipitation correction term can be applied on a daily or an hourly basis.²⁶

For the daily basis, Equation 1 becomes:

$$E_{ext} = \left[k \left(\frac{sL}{2} \right)^{0.65} \left(\frac{W}{3} \right)^{1.5} - C \right] \left(1 - \frac{P}{4N} \right) \quad (2)$$

where k , sL , W , and C are as defined in Equation 1 and

- E_{ext} = annual or other long-term average emission factor in the same units as k ,
- P = number of “wet” days with at least 0.254 mm (0.01 in) of precipitation during the averaging period, and
- N = number of days in the averaging period (e.g., 365 for annual, 91 for seasonal, 30 for monthly)

Note that the assumption leading to Equation 2 is based by analogy with the approach used to develop long-term average unpaved road emission factors in Chapter 6. However, Equation 2 above incorporates an additional factor of “4” in the denominator to account for the fact that paved roads dry more quickly than unpaved roads and that the precipitation may not occur over the complete 24-hour day.

Table 5-3. Ubiquitous Silt Loading Default Values with Hot Spot Contributions from Anti-Skid Abrasives for Public Paved Roads (g/m²)

Average Daily Traffic (ADT) Category	< 500	500-5,000	5,000-10,000	> 10,000
Ubiquitous baseline (g/m ²)	0.6	0.2	0.06	0.03 0.015 limited access
Ubiquitous winter baseline multiplier during months with frozen precipitation	X4	X3	X2	X1
Initial peak additive contribution from application of antiskid abrasive (g/m ²)	2	2	2	2
Days to return to baseline conditions (assume linear decay)	7	3	1	0.5

For the hourly basis, Equation 1 becomes:

$$E_{ext} = \left[k \left(\frac{sL}{2} \right)^{0.65} \left(\frac{W}{3} \right)^{1.5} - C \right] \left(1 - \frac{1.2P}{N} \right) \quad (3)$$

where k, sL, and W, and C are as defined in Equation 1 and

- E_{ext} = annual or other long-term average emission factor in the same units as k ,
- P = number of hours with at least 0.254 mm (0.01 in) of precipitation during the averaging period, and
- N = number of hours in the averaging period (e.g., 8,760 for annual; 2,124 for season; 720 for monthly).

Note that the assumption leading to Equation 3 is based by analogy with the approach used to develop long-term average unpaved road emission factors in Chapter 6. Also note that in the hourly moisture correction term $(1 - 1.2P/N)$ for Equation 3, the 1.2 multiplier is applied to account for the residual mitigative effect of moisture. For most applications, this equation will produce satisfactory results. However, if the time interval for which the equation is applied is short (e.g., 1 hour or 1 day), the application of this multiplier makes it possible for the moisture correction term to become negative. This will result in calculated negative emissions which is not realistic. Users should expand the time interval to include sufficient “dry” hours such that negative emissions are not calculated. For the special case where this equation is used to calculate emissions on an hour by hour basis, such as would be done in some emissions modeling situations, the moisture correction term should be modified so that the moisture correction “credit” is applied to the first hours following cessation of precipitation. In this special case, it is suggested that this 20% “credit” be applied on a basis of one hour credit for each hour of precipitation up to a maximum of 12 hours.

Maps showing the geographical distribution of “wet” days on an annual basis for the United States based on meteorological records on a monthly basis are available in the *Climatic Atlas of the United States*.²³ Alternative sources include other Department of Commerce publications such as local climatological data summaries. The National Climatic Data Center (NCDC) offers several products that provide hourly precipitation data. In particular, NCDC offers a *Solar and Meteorological Surface Observation Network 1961-1990* (SAMSON) CD-ROM, which contains 30 years worth of hourly meteorological data for first-order National Weather Service locations. Whatever meteorological data are used, the source of that data and the averaging period should be clearly specified. It is emphasized that the simple assumption underlying Equations 2 and 3 has not been verified in any rigorous manner. For that reason, the quality ratings for Equations 2 and 3 should be downgraded one letter from the rating that would be applied to Equation 1.

Table 5-3 presents recommended default silt loadings for normal baseline conditions and for wintertime baseline conditions for public paved roads in areas that experience

frozen precipitation with periodic application of antiskid material.²⁴ The winter baseline is represented as a multiple of the nonwinter baseline, depending on the average daily vehicle traffic count (ADT) value for the road in question. As shown, a multiplier of 4 is applied for low volume roads (< 500 ADT) to obtain a wintertime baseline silt loading of $4 \times 0.6 = 2.4 \text{ g/m}^2$.

It is suggested that an additional (but temporary) silt loading contribution of 2 g/m^2 occurs with each application of antiskid abrasive for snow/ice control. This was determined based on a typical application rate of 500 lb per lane mile and an initial silt content of 1%. Ordinary rock salt and other chemical deicers add little to the silt loading because most of the chemical dissolves during the snow/ice melting process.

To adjust the baseline silt loadings for mud/dirt trackout, the number of trackout points is required. It is recommended that in calculating PM₁₀ emissions, six additional miles of road be added for each active trackout point from an active construction site, to the paved road mileage of the specified category within the county. In calculating PM_{2.5} emissions, it is recommended that three additional miles of road be added for each trackout point from an active construction site. It is suggested the number of trackout points for activities other than road and building construction areas be related to land use. For example, in rural farming areas, each mile of paved road would have a specified number of trackout points at intersections with unpaved roads. This value could be estimated from the unpaved road density (miles per square mile).

The use of a default value from Table 5-3 should be expected to yield only an order-of-magnitude estimate of the emission factor. Public paved road silt loadings are dependent upon: traffic characteristics (speed, ADT, and fraction of heavy vehicles); road characteristics (curbs, number of lanes, parking lanes); local land use (agriculture, new residential construction) and regional/seasonal factors (snow/ice controls, wind blown dust). As a result, the collection and use of site-specific silt loading data is highly recommended. In the event that default silt loading values are used, the quality ratings for the equation should be downgraded two levels.

Limited access roadways (high speed freeways) pose severe logistical difficulties in terms of surface sampling, and few silt loading data are available for such roads. Nevertheless, the available data do not suggest great variation in silt loading for limited access roadways from one part of the country to another. For annual conditions, a default value of 0.015 g/m^2 is recommended for limited access roadways.^{9,22} Even fewer of the available data correspond to worst-case situations, and elevated loadings are observed to be quickly depleted because of high traffic speeds and high ADT rates. A default value of 0.2 g/m^2 is recommended for short periods of time following application of snow/ice controls to limited access roads.²²

The limited data on silt loading values for industrial roads have shown as much variability as public roads. Because of the variations of traffic conditions and the use of preventive mitigative controls, the data probably do not reflect the full extent of the potential variation in silt loading on industrial roads. However, the collection of site

specific silt loading data from industrial roads is easier and safer than for public roads. Therefore, the collection and use of site-specific silt loading data is preferred and is highly recommended. In the event that site-specific values cannot be obtained, an appropriate value for an industrial road may be selected from the mean values given in Table 5-4, but the quality rating of the equation should be reduced by two levels.

5.3 Emission Estimation: Alternate Methodology

This section was adapted from Section 7.9 of CARB's Emission Inventory Methodology. Section 7.9 was last updated in July 1997.

The paved road dust category includes emissions of fugitive dust particulate matter entrained by vehicular travel on paved roads. The California Air Resources Board (CARB) estimates road dust emissions for the following four classes of roads: (1) freeways/expressways, (2) major streets/highways, (3) collector streets, and (4) local streets. Dust emissions from vehicle travel on paved roads are computed using the emission factor equation provided in AP-42 (see Section 5.2 of this document). Inputs to the paved road dust equation were developed from area-specific roadway silt loading and average vehicle weight data measured by Midwest Research Institute (MRI, 1996).²⁹

Data from states and air districts are used to estimate county specific VMT (vehicle miles traveled) data.^{30, 31} State highway³² data are used to estimate the fraction of travel on each of the four road types in each county.

The statewide average vehicle weight for California is assumed to be 2.4 tons. This estimate is based on an informal traffic count estimated by MRI while they were performing California silt loading measurements.²⁹ CARB assumes the following silt loadings for the four road categories: 0.02 g/m² for freeways, 0.035 g/m² for major roads, and 0.32 g/m² for collector and local roads.³³ The PM_{2.5}/PM₁₀ ratio for paved road dust published by CARB is 0.169.³⁴

**Table 5-4 Typical Silt Content and Loading Values for Paved Roads at Industrial Facilities^a
(Metric And English Units).**

Industry	No. of sites	No. of samples	Silt content (%)		No. of travel lanes	Total loading x 10 ⁻³			Silt loading (g/m ²)	
			Range	Mean		Range	Mean	Units ^b	Range	Mean
Copper smelting	1	3	15.4-21.7	19.0	2	12.9-19.5 45.8-69.2	15.9 55.4	kg/km lb/mi	188-400	292
Iron and steel production	9	48	1.1-35.7	12.5	2	0.006-4.77 0.020-16.9	0.495 1.75	kg/km lb/mi	0.09-79	9.7
Asphalt batching	1	3	2.6-4.6	3.3	1	12.1-18.0 43.0-64.0	14.9 52.8	kg/km lb/mi	76-193	120
Concrete batching	1	3	5.2-6.0	5.5	2	1.4-1.8 5.0-6.4	1.7 5.9	kg/km lb/mi	11-12	12
Sand and gravel processing	1	3	6.4-7.9	7.1	1	2.8-5.5 9.9-19.4	3.8 13.3	kg/km lb/mi	53-95	70
Municipal solid waste landfill	2	7	—	—	2	—	—	—	1.1-32.0	7.4
Quarry	1	6	—	—	2	—	—	—	2.4-14	8.2

^a References 1-2, 5-6, 11-13. Dashes indicate information not available.

^b Multiply entries by 1,000 to obtain stated units; kilograms per kilometer (kg/km) and pounds per mile (lb/mi).

Temporal activity is assumed to be the same as on-road vehicle travel: uniform in spring and fall, increasing slightly in summer, and decreasing slightly in winter. The monthly temporal profile below shows this trend. The weekly and daily activities are estimated to have higher activities on weekdays and during daylight hours.

ALL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
100	7.7	7.7	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	7.7

This alternative methodology utilized by CARB is subject to the following assumptions and limitations:

1. The current AP-42 emission factor assumes that road dust emissions are proportional to VMT, roadway silt loading, and average vehicle weight.
2. It may be necessary to assume that virtually the same silt loading values apply throughout the state because of lack of measured silt loadings.
3. The methodology assumes that roadway silt loading, and therefore the emission factor, varies by the type of road.
4. It is assumed that the EPA particle size multiplier (i.e., the ‘k’ factor in the AP-42 equation) reasonably represents the size distribution of paved road dust.
5. The average vehicle fleet weight is assumed to be 2.4 tons in California (except for the SCAQMD that assumes 3 tons).
6. For freeway and major roads, emissions growth is assumed to be proportional to changes in roadway centerline mileage. For collector and local roads, emissions growth is assumed proportional to changes in VMT.

5.4 Demonstrated Control Techniques

Because of the importance of road surface silt loading, control techniques for paved roads attempt either to prevent material from being deposited onto the surface (preventive controls) or to remove from the travel lanes any material that has been deposited (mitigative controls). Covering of loads in trucks and the paving of access areas to unpaved lots or construction sites are examples of preventive measures. Examples of mitigative controls include vacuum sweeping, water flushing, and broom sweeping and flushing. Actual control efficiencies for any of these techniques can be highly variable. Locally measured silt loadings before and after the application of controls is the preferred method to evaluate controls. It is particularly important to note that street sweeping of gutters and curb areas may actually increase the silt loading on the traveled portion of the road. Redistribution of loose material onto the travel lanes will actually produce a short-term increase in the emissions.

In general, preventive controls are usually more cost effective than mitigative controls. The cost-effectiveness of mitigative controls falls off dramatically as the size of an area to be treated increases. The cost-effectiveness of mitigative measures is also unfavorable if only a short period of time is required for the road to return to equilibrium

silt loading condition. That is to say, the number and length of public roads within most areas of interest preclude any widespread and routine use of mitigative controls. On the other hand, because of the more limited scope of roads at an industrial site, mitigative measures may be used quite successfully (especially in situations where truck spillage occurs). Note; however, that public agencies could make effective use of mitigative controls to remove sand/salt from roads after the winter ends.

Because available controls will affect the silt loading, controlled emission factors may be obtained by substituting controlled silt loading values into the appropriate equation. (Note that emission factors from controlled industrial roads were used in the development of the equation.) The collection of surface loading samples from treated, as well as baseline (untreated) roads provides a means to track effectiveness of the controls over time.

Table 5-5 summarizes tested control measures and reported control efficiencies for measures that reduce the generation of fugitive dust from paved roads.

5.5 Regulatory Formats

Fugitive dust control options have been embedded in many regulations for state and local agencies in the WRAP region. Regulatory formats specify the threshold source size that triggers the need for control application. Example regulatory formats for several local air quality agencies in the WRAP region are presented in Table 5-6. The website addresses for obtaining information on fugitive dust regulations for local air quality districts within California, for Clark County, NV, and for Maricopa County, AZ, are as follows:

- Districts within California: www.arb.ca.gov/drdb/drdb.htm
- Clark County, NV: www.co.clark.nv.us/air_quality/regs.htm
- Maricopa County, AZ: www.maricopa.gov/envsvc/air/ruledesc.asp

Table 5-5. Control Efficiencies for Control Measures for Paved Roads³⁵⁻³⁷

Control measure	Source component	PM10 control efficiency	References/comments
Implement street sweeping program with non-efficient vacuum units (14-day frequency)	Local streets	7%	MRI, September 1992. For non-PM10 efficient sweepers based on 55% efficient sweeping, 5.5 day equilibrium return time and CA-VMT weighted sweeping frequency (7 to 30 days)
	Arterial/collector streets	11%	
Implement street sweeping program with PM10 efficient vacuum units (14-day frequency)	Local streets	16%	MRI, September 1992. For PM10 efficient sweepers, based on 86% efficient sweeping, 8.6 day return time, and CA-VMT weighted sweeping frequency (7 to 30 days)
	Arterial/collector streets	26%	
Require streets to be swept by non-efficient vacuum units (once per month frequency)	Local streets	4%	MRI, September 1992. For non-PM10 efficient sweepers based on 55% efficient sweeping, 5.5 day equilibrium return time and CA-VMT weighted sweeping frequency (7 to 30 days)
	Arterial/collector streets	4%	
Require streets to be swept by PM10 efficient vacuum units (once per month frequency)	Local streets	9%	MRI, September 1992. For PM10 efficient sweepers, based on 86% efficient sweeping, 8.6 day return time, and CA-VMT weighted sweeping frequency (7 to 30 days)
	Arterial/collector streets	9%	
Require wind- or water-borne deposition to be cleaned up within 24 hours after discovery	All Streets	100%	Assumes total cleanup of spill on roadway before traffic resumes
Install pipe-grid trackout-control device	Mud/dirt carryout	80%	Sierra Research, 2003.
Install gravel bed trackout apron (3 in deep, 25 ft long and full road width)	Mud/dirt carryout	46%	MRI, April 2001
Require paved interior roads to be 100 foot long and full road width, or add 4 foot shoulder for paved roads	Mud/dirt carryout	42%	MRI, April 2001

Table 5-6. Example Regulatory Formats for Paved Roads

CAPCOA				Clark County, NV				Maricopa County, AZ			
Control Measure	Goal	Threshold	Agency	Control Measure	Goal	Threshold	Agency	Control Measure	Goal	Threshold	Agency
Requires paved shoulders. As an option to paving or vegetation requirements, oils or chemical dust suppressants can be used and must be maintained	Limit visible dust emissions to 20% opacity	Roads with average daily vehicle trips (ADVT) of 500 or more	SJVAPCD Rule 8061 11/15/2001	Requires paved travel section, and 4 ft of paved or stabilized shoulder on each side of travel section. Shoulders shall be paved with dust palliative or gravel (2")	Comply with stabilization standard: limit shoulder visible dust emissions to 20% opacity; limit silt loading to 0.33 oz/ft2	Newly constructed or modified paved roads	Hydrographic Basins 212, 216, 217 Sect. 93 Air Quality Reg. 06/22/2000	Limit spd limit to 15 mph or less	Limit track-out from bulk material transport; reduce particulate matter emissions from paved roads	Work site roads, crossing paved roads transporting bulk materials; during disk and blading ops	Maricopa County Rule 310 04/07/2004
Require average shoulder width to be 4 ft. Curbing adjacent to and contiguous with a paved lane or shoulder can be used in lieu of shoulder width requirements. Intersections, auxiliary entry and exit lanes may be constructed adjacent to and contiguous with a paved roadway in lieu of shoulder requirements	Limit visible dust emissions to 20% opacity	Roads with average daily vehicle trips (ADVT) 500-3000	SJVAPCD Rule 8061 11/15/2001	Medians shall be constructed as follows: with curbing, solid paving, apply dust palliatives, or with material that prevent track-out such as landscaping or decorative rock	Comply with stabilization standard: limit shoulder visible dust emissions to 20% opacity; limit silt loading to 0.33 oz/ft2	Newly constructed or modified paved roads	Hydrographic Basins 212, 216, 217 Sect. 93 Air Quality Reg. 06/22/2000				

Table 5-6. Example Regulatory Formats for Paved Roads (Continued)

CAPCOA				Clark County, NV				Maricopa County, AZ			
Control Measure	Goal	Threshold	Agency	Control Measure	Goal	Threshold	Agency	Control Measure	Goal	Threshold	Agency
Require average shoulder width to be 8 ft. Curbing adjacent to and contiguous with a paved lane or shoulder can be used in lieu of shoulder width requirements. Intersections, auxiliary entry and exit lanes may be constructed adjacent to and contiguous with a paved roadway in lieu of shoulder requirements	Limit visible dust emissions to 20% opacity	Roads with average daily vehicle trips (ADVT) greater than 3000	SJVAPCD Rule 8061 11/15/2001								
Medians constructed with minimum 4 ft shoulder widths adjacent to traffic lanes, and landscaped	Meet stabilized surface requirements and limit visible dust emissions to 20% opacity	Roads with average daily vehicle trips (ADVT) of 500 or more and medians part of roadway	SJVAPCD Rule 8061 11/15/2001								
Medians constructed with curbing		Where speed limits are below 45 mph	SJVAPCD Rule 8061 11/15/2001								

Table 5-6. Example Regulatory Formats for Paved Roads (Continued)

CAPCOA				Clark County, NV				Maricopa County, AZ			
Control Measure	Goal	Threshold	Agency	Control Measure	Goal	Threshold	Agency	Control Measure	Goal	Threshold	Agency
Curbing and shoulder width requirements in event of contingency notification	Maintain stabilized surface; limit paved road dust	Roads with average daily vehicle trips (ADVT) of 500 or more	SCAQMD Rule 1186 9/10/1999								
Require average shoulder width to be 4 ft.	Limit visible dust emissions to 20% opacity	Roads with average daily vehicle trips (ADVT) 500-3000	SCAQMD Rule 1186 9/10/1999								
Require average shoulder width to be 8 ft.	Limit visible dust emissions to 20% opacity	Roads with average daily vehicle trips (ADVT) greater than 3000	SCAQMD Rule 1186 9/10/1999								
Must pave median area with typical roadway materials	Maintain stabilized surface	Roads with average daily vehicle trips (ADVT) of 500 or more and speed limits greater than 45	SCAQMD Rule 1186 9/10/1999								

Table 5-6. Example Regulatory Formats for Paved Roads (Continued)

CAPCOA				Clark County, NV				Maricopa County, AZ			
Control Measure	Goal	Threshold	Agency	Control Measure	Goal	Threshold	Agency	Control Measure	Goal	Threshold	Agency
Requires medians be landscaped with ground cover and there is curbing, or medians treated with chemical stabilizers	Maintain stabilized surface	Roads with average daily vehicle trips (ADVT) of 500 or more and speed limits less than 45	SCAQMD Rule 1186 9/10/1999								

5.6 Compliance Tools

Compliance tools assure that the regulatory requirements, including application of dust controls, are being followed. Three major categories of compliance tools are discussed below.

Record keeping: A compliance plan is typically specified in local air quality rules and mandates record keeping of source operation and compliance activities by the source owner/operator. The plan includes a description of how a source proposes to comply with all applicable requirements, log sheets for daily dust control, and schedules for compliance activities and submittal of progress reports to the air quality agency. The purpose of a compliance plan is to provide a consistent reasonable process for documenting air quality violations, notifying alleged violators, and initiating enforcement action to ensure that violations are addressed in a timely and appropriate manner.

Site inspection: This activity includes (1) review of compliance records, (2) proximate inspections (sampling and analysis of source material), and (3) general observations. An inspector can use photography to document compliance with an air quality regulation.

On-site monitoring: EPA has stated that “An enforceable regulation must also contain test procedures in order to determine whether sources are in compliance.” Monitoring can include observation of visible plume opacity, surface testing for crust strength and moisture content, and other means for assuring that specified controls are in place.

Table 5-7 summarizes the compliance tools that are applicable to paved roads.

Table 5-7. Compliance Tools for Paved Roads

Record keeping	Site inspection/monitoring
Road map; traffic volumes, speeds, and patterns; vacuum sweeping, mud/dirt trackout precautions, spill cleanup, erosion control, tarping of haul trucks; curbing of roads; application of sand/salt for anti-skid operations; dust suppression equipment and maintenance records.	Sampling of silt loading on paved road surfaces; counting of traffic volumes; observations of vacuum sweeping, high dust emission areas (including track-on and wash-on points), road curbing/shoulders; observation of dust plume opacity (visible emissions) exceeding a standard; real-time portable monitoring of PM.

5.7 Sample Cost-Effectiveness Calculation

This section is intended to demonstrate how to select a cost-effective control measure for fugitive dust originating from paved roads. A sample cost-effectiveness calculation is presented below for a specific control measure (PM10 efficient street sweeper) to illustrate the procedure. The sample calculation includes the entire series of steps for estimating uncontrolled emissions (with correction parameters and source extent), controlled emissions, emission reductions, control costs, and control cost-effectiveness values for PM10 and PM2.5. In selecting the most advantageous control

measure for construction and demolition, the same procedure is used to evaluate each candidate control measure (utilizing the control measure specific control efficiency and cost data), and the control measure with the most favorable cost-effectiveness and feasibility characteristics is identified.

Sample Calculation for Paved Roads (Arterial Road Through Industrial Area)

Step 1. Determine source activity and control application parameters.

Vehicles/day	5,000
Average vehicle speed (mph)	40
Length of road (miles)	10
Control Measure	Use of PM10 efficient street sweepers
Control application/frequency	Once per month
Economic Life of Control System (yr)	10
Control Efficiency	9.2%

The number of vehicles per day, the average vehicle speed, road length, and economic life are assumed values for illustrative purposes. Street sweeping, using PM10 efficient sweepers has been chosen as the applied control measure. The control application/frequency and control efficiency are default values provided by MRI, 1992.³⁶

Step 2. Calculate Emission Factor. The PM2.5 and PM10 emission factors are calculated from the AP-42 equation utilizing the appropriate correction parameters.

$$E = (k(sL/2)^{0.65} (W/3)^{1.5} - C) * (1 - (P/1460))$$

k—PM2.5 (lb/VMT)	0.004
k—PM10 (lb/VMT)	0.016
sL—silt loading (g/m ²)	2
W—average vehicle weight (tons)	5
C—PM2.5 (lb/VMT)	0.00036
C—PM10 (lb/VMT)	0.00047
P—wet days/yr (1/yr)	50

- $E_{PM10} = 0.033 \text{ lb/VMT}$
- $E_{PM2.5} = 0.0080 \text{ lb/VMT}$

Step 3. Calculate Uncontrolled PM Emissions. The emission factors (calculated in Step 2) are multiplied by the number of vehicles per day and the road length (both under activity data) and then multiplied by 365/2,000 to compute the annual emissions, as follows:

Annual emissions = (Emission Factor x Vehicles/day x Road length x 365/2,000)

- Annual PM10 Emissions = $(0.03 \times 5,000 \times 10) \times 365 / 2,000 = 299 \text{ tons}$
- Annual PM2.5 Emissions = $(0.03 \times 5,000 \times 10) \times 365 / 2,000 = 72.7 \text{ tons}$

Step 4. Calculate Controlled PM Emissions. The uncontrolled emissions estimate (calculated in Step 3) is multiplied by the percentage that uncontrolled emissions are reduced, as follows:

Controlled emissions = Uncontrolled emissions x (1 – Control Efficiency),
where CE = 9.2% (as seen under activity data)

For this example, we have selected PM10 efficient street sweeping as our control measure. Based on a control efficiency estimate of 9.2%, the annual PM10 emissions are calculated to be:

Annual Controlled PM10 emissions = (299 tons) x (1 – 0.092) = 272 tons
Annual Controlled PM2.5 emissions = (72.7 tons) x (1 – 0.092) = 66.0 tons

Step 5. Determine Annual Cost to Control PM Emissions.

Capital costs (\$)	15,200
Operating/Maintenance costs (\$)	16,000
Overhead costs (\$)	8,000
Enforcement/Compliance costs (\$)	500
Annual Interest Rate	3%
Capital Recovery Factor	0.12
Total Cost (\$)	39,700
Annualized Cost (\$/yr)	26,282

The Capital costs, the Operating/Maintenance costs, and the Enforcement/Compliance costs are default values determined from current sources (e.g. Sierra Research, 2003³⁷).

The Overhead costs are typically one-half of the Operating/Maintenance costs.
Overhead costs = \$16,000/2 = \$8,000.

The Annual Interest Rate (AIR) is based on the most up to date information and sources.

The Capital Recovery Factor (CRF) is figured by multiplying the Annual Interest Rate by 1 plus the AIR, raised to the exponent of the Economic life of the control system. Then divide by 1 plus the AIR to the Economic life minus 1, as follows:

Capital Recovery Factor = $AIR \times (1 + AIR)^{\text{Economic life}} / (1 + AIR)^{\text{Economic life}} - 1$

Capital Recovery Factory = $3\% \times (1 + 3\%)^{10} / (1 + 3\%)^{10} - 1 = 0.12$

The Total Cost is the sum of the Capital costs, Operating/Maintenance costs, Overhead costs, and the Enforcement/Compliance costs:

Total Cost = Capital costs + Operating/Maintenance costs + Overhead + Enforcement/Compliance costs

Total Cost = 15,200 + 16,000 + 8,000 + 500 = \$39,700

The Annualized Cost is calculated by adding the product of the Capital Recovery Factor and the Capital costs to the Operating/Maintenance costs, the Overhead costs and the Enforcement/Compliance costs:

$$\text{Annualized Cost} = (\text{CRF} \times \text{Capital costs}) + \text{Operating/Maintenance} + \text{Overhead costs} + \text{Enforcement/Compliance costs}$$
$$\text{Annualized Cost} = (0.12 \times 15,200) + 16,000 + 8,000 + 500 = \$26,300$$

Step 6. Calculate Cost Effectiveness. Cost effectiveness is calculated by dividing the annualized cost by the emissions reduction. The emissions reduction is determined by subtracting the controlled emissions from the uncontrolled emissions:

$$\text{Cost effectiveness} = \text{Annualized Cost} / (\text{Uncontrolled emissions} - \text{Controlled emissions})$$
$$\begin{aligned} \text{Cost effectiveness for PM}_{10} \text{ emissions} &= \$26,300 / (299 - 272) = \$960/\text{ton} \\ \text{Cost effectiveness for PM}_{2.5} \text{ emissions} &= \$26,300 / (72.7 - 66.0) = \$3,930/\text{ton} \end{aligned}$$

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